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# Risk management for jatropha curcas based biodiesel industry of Panzhihua Prefecture in Southwest China

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ABSTRACT

As one of the most important regions selected for jatropha biodiesel industry in Southwest China, Panzhihua has received very high and optimistic expectations. However, current situation suggests that jatropha in Panzhihua has not changed local energy scenario and the industry has been threatened by many risks. Moreover, the study of risk management on jatropha biodiesel industry is largely absent. Therefore, this study applies the idea of risk management to jatropha biodiesel industry in Panzhihua, covering complete procedures with respect to risk identification, risk assessment, risk response and risk monitoring. By risk identification, this study reveals 14 key risks which have critical influences upon this industry. The risk assessment determines the risks which are ranked as the first status to take risk response: risks of low seed yield, insect pests and diseases, poor implementation for the plans set for establishing jatropha biodiesel refining capacity, low profitability for jatropha biodiesel production, no local gas station selling jatropha biodiesel, low comparative price of biodiesel versus diesel, insufficient subsidy for farmers to conduct cultivation, insufficient subsidy for conducting biodiesel production. Accordingly, the measures for risk reduction have been given. It is a very long way to cover before the jatropha biodiesel to be realized in Panzhihua. The urgent tasks for the local governments in Panzhihua are just to maintain but adjust their ambitious plans, enhance the demonstration effects of industrial projects at an appropriate and economic scale.



**Contents**



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## 1. Introduction

Due to relative high oil content of seed, jatropha curcas (named as jatropha herefrom) has been regarded as an ideal feedstock for biodiesel. It can alleviate dependency on oil import and excess use of fossil fuels [1]. Besides this attribute, jatropha is also effective for the prevention of soil erosion, ecological restoration, improvement of rural economy [2]. Owing to its manifold utilizations, many developing countries like India have adopted aggressive strategies on jatropha biodiesel industry [3]. Following in line with this trend, the State Forest Administration of China has raised the 11th five-year plan (2006–2010) for cultivating 20 million hectares of woody oil plants to meet 6 million tonnes of biodiesel supply [4]. Under this plan, jatropha plantations would expand to 0.4 million hectares mainly in Southwest China [4].

Because of limited arable land and dense population, the plantation of food-based energy crops has been restricted in China [5]. On the contrary, with attributes of drought-resistance, jatropha can grow on marginal and barren land without jeopardizing food security. Therefore, jatropha has received high expectation as well as much attention in China. Consequently, various jatropha-based projects have been put forward by provincial governments of Sichuan, Yunnan, Guizhou [5]. These projects include ambitious plans for seedlings cultivation, nurseries and plantations construction, biodiesel refining and processing infrastructures construction [5,6]. However, due to multiple factors, most of the targets have become unfulfilled promises [7]. It seems that the outlook of this industry is less promising.

The Panzhihua Prefecture is located in the south of Sichuan Province. It belongs to semi-arid climate in the south subtropical climate zone [8]. The yearly mean temperature in Panzhihua is regarded as the highest region in Sichuan [9]. It is also considered as the driest place in Sichuan. The afforestation in Panzhihua is thus very difficult [10], especially in the dry-hot river valley. However, as a perennial [1] or an indigenous plant [11], jatropha shows good ecological adaptability and has broad distribution under the conditions of dry-hot climate and barren land in Panzhihua. It is reported that there are about 13,333 hectares of jatropha in this region [12]. As one of the earliest and largest areas selected for the construction of jatropha biodiesel industry in China [10], Panzhihua have very important demonstrational value for other similar places in China. However, most of the industrial plans which are set by local governments and enterprises have not been completed and more seriously, current developmental status of jatropha biodiesel industry in Panzhihua shows that it largely deviates from the expected scenario [10]. In 2008, a famous newspaper of Sichuan reported the reasons as to why a famous international biofuel company abandoned its jatropha biodiesel investment in Panzhihua [13]. Accordingly, to a certain degree, the jatropha-based biodiesel industry in Panzhihua actually has confronted many risks. However, without in-depth and detailed risk management before decision-making, underlying risk factors could critically damage the prospect of this industry. Therefore, in order to raise the risk concern on the industry of jatropha biodiesel in Panzhihua and to cool the enthusiasm both from the governments and corporations for massive construction and rapid expansion of the industrial bases, it is rather necessary and urgent to conduct a systematic risk management. To date, much focus from literature and decision-makers is on the advantages of jatropha. However, risk study on jatropha is largely absent. Furthermore, very limited literature on risk management of jatropha biodiesel industry could be found. Therefore, this study tries to apply the idea of risk management to jatropha biodiesel industry in Panzhihua, covering complete process with respect to risk identification, risk assessment, risk response and risk monitoring. The objectives of this paper will identify the risks which have critical influences on the industry and determine their ranking orders for risk response. More importantly, this study will highlight the awareness for different stakeholders to establish a robust and frequent risk monitoring mechanism.

## 2. Research background

The Panzhihua Prefecture is situated at latitude 26°05′–27°21′N and longitude 101°15′–102°08′E [14], which is adjacent to Yunnan Province on the southwest (see Fig. 1). It is located at the confluence of the Jinsha River and the Yalong River [14]. The mean annual temperature in Panzhihua could reach from 19.7 °C to 20.5 °C [14]. The distribution pattern of rainfall shows imbalance between the rainy season and the dry season. Most of the annual rainfall is received in rainy season, which is from June to October [14,15]. Compared


**Fig. 1.** The location of Panzhihua in China.

with other places in Sichuan Province, Panzhihua has lower precipitation and higher evaporation. In the dry-hot river valley, the mean yearly rainfall varies from 767.3 mm to 1070.1 mm [15]. However, the mean annual evaporation water loss could range from 2054.3 mm to 2438.6 mm [15]. The sunlight duration in Panzhihua could reach 2300–2700 h and the mean annual intensity value of solar radiation could vary from 5600 MJ/$m^2$ to 6300 MJ/$m^2$ [16].

Due to seasonal shortage of rainfall and severe water evaporation, forest cultivation and agricultural activity in the dry-hot valley of Panzhihua is extremely difficult. Therefore, intensive cultivation is mainly carried out in the mesa zone or lower part of the mountain where the water supply is relatively sufficient [17]. Rice and maize are the primary grain crops. Because of good thermal and light conditions, there are many varieties of cash crops in Panzhihua. These economical crops include sugarcane, off-seasonal vegetables, tobacco, edible oil crops like peanut and rape, medicinal crops. Furthermore, due to vertical zonality of climate in Panzhihua, the fruit variety is also plentiful. Indeed, most kinds of fruit planted in the temperate zone, subtropical zone and torrid zone could be found in Panzhihua [18]. In 2009, the rural per capital net income in Panzhihua reached 5474.93 RMB [19]. It was ranked as the third highest region among all 21 prefectures in Sichuan Province [20].

## 3. A review on risk management of jatropha biodiesel industry

There are very limited studies on risk management of jatropha biodiesel industry in literature, however, some researchers have raised their concerns on existing problems of this industry in their papers. To a large extent, these mentioned issues could be regarded as risk sources or risk factors. Therefore, these studies could be considered as risk identification, which is a part of risk management. In this section, we overview the raised problems in current literature and then review present status of risk management of this industry. In order to enhance comprehensive and comparative understanding of existent issues or risks in this industry, our review do include papers both from Chinese and international journals.

### *3.1. Mentioned issues on jatropha biodiesel industry in current studies*

#### *3.1.1. Issues on the industry from Chinese journals*

*3.1.1.1. Land issues.* Land issues refer to quantity and quality of land to meet massive commercial planting of jatropha [5,21]. Weyerhaeuser et al. [5] point out that very limited better land could be used for jatropha planting in Southwest China, because much more barren or marginal land exists. Therefore, Weyerhaeuser et al. [5] doubt as to whether seed oil content and yield could reach expected target on poor land. Weyerhaeuser et al. [5] also indicate that a land use conflict will occur when jatropha is cultivated on cropland. Furthermore, Wu et al. [21] indicate that it is impossible to fulfill the plantation coverage plan of 1,667,000 hectares in Southwest China which is set by central government. Wu et al. [21] evaluate the potential suitable land for jatropha planting according to the limiting factors of temperature, water condition, soil condition as well as land slope. Wu et al. [21] further demonstrate that only 70,000 hectares is suitable for planning jatropha in Sichuan Province, Yunnan Province and Guizhou Province, because poor land can cause low seed oil content and low seed yield.

*3.1.1.2. Limited refining capacity.* Weyerhaeuser et al. [5] show their deep concern on very limited biodiesel refining capacity at present and in the future in Southwest China. Weyerhaeuser et al. [5] indicate that Sichuan has about 15,000 tonnes refining capacity, Guizhou has 20,000 tonnes and Yunnan has no refining capacity. Weyerhaeuser et al. [5] also point out that rapeseed and waste cooking oil are the main feedstocks for refining in Southwest China. Due to this issue, it is rather difficult to meet the plan for jatropha biodiesel production which has been established by local governments. Furthermore, due to monetary shortage, the infrastructures construction for jatropha biodiesel refining and processing plants have not been actualized [5,13]. Particularly, there is no refining and processing plant for jatropha biodiesel production in Panzhihua and several state-owned energy companies have halted their programs on the plant construction for jatropha biodiesel production [10,13].

*3.1.1.3. Basic research issues.* The unit seed yield and seed oil content of jatropha range largely and therefore seriously shape the economic benefit of jatropha biodiesel industry in China.

Weyerhaeuser et al. [5], Lu and Wang [22], Zhang et al. [23], Yu et al. [24], Fei et al. [28], Luo and Zhang [29], He et al. [30] all indicate that low seed yield and low seed oil content is one of the main obstacles to develop jatropha biodiesel industry. Actually, the main effective solution for seed yield and seed oil content improvement is by variety breeding. However, in China, variety breeding for jatropha is lagging behind its massive plantation. Lu and Wang [22] raise cultivar selection as the main weakness in their analysis on jatropha biodiesel industry in Yunnan Province. Zhang et al. [23] and Yu et al. [24] also point out that variety breeding is one of the main hurdles for jatropha planting.

Actually, current basic research for variety breeding mainly concentrates on the survey on germplasm resources of wild jatropha plants [23]. However, studies on genetic modification for variety breeding are very few in Chinese journals [23]. In China, jatropha basic researches are still at an early stage in identifying and annotating genes which are related with high seed yield and high oil content. Particularly, studies on cloning, expression and biological function annotation for jatropha genes which are responsible for economical traits are largely absent in China.

*3.1.1.4. Technical issues.*

- Technical issues refer to jatropha cultivation

The main objective of cultivation is to largely improve the unit seed yield of jatropha for commercial use. Therefore, the techniques of jatropha cultivation refers to many field practices such as propagation, site preparation, tree density and canopy control, insects and diseases control, fertilization and irrigation management, cropping treatments [23–25]. Yu et al. [24], Wu and Li [31] point out that poor research of planting techniques, poor management for planting base are the limiting factors to conduct a massive construction for jatropha plantation. However, very limited studies try to precisely and scientifically demonstrate the influence of field operation on the seed yield of jatropha in China. Moreover, the results of detailed field observation on seed yield under different treatments of cultivation techniques have not been indicated and reported. For example, data on tree density for jatropha cultivation, canopy pruning intensity and frequency, insecticide effect as well as fertilization and irrigation efficiency are largely absent in literature. Actually, in China, a special technique standard system which could integrate and quantifiably optimize all field operations for large-scale jatropha cultivation has not established till date [22–25].

Particularly, insects and diseases control is one of the most important technical issues which could seriously shape jatropha cultivation. Although jatropha shows good resistance to negative external factors [25], it is confirmed that monocropping could result in the spread of insects and diseases. Yu et al. [26] find 24 species of insects and diseases on jatropha in Panzhihua, Wu et al. [27] also discover 8 types of diseases and 7 species of insects on jatropha in the dry-hot valley of Yunnan Province. As a matter of

fact, the utilization of insecticide and fungicide is a common, but ineffective control measure in China. Besides chemical prevention, a comprehensive control techniques system which integrates the special and abroad-spectrum insecticide and fungicide utilization, biological control, biodiversity improvement for jatropha based field ecosystem and appropriate tree density management has not been established in China.

- Technical issues refer to jatropha biodiesel production.

The technology for jatropha biodiesel production refers to refining and processing technology, product quality standard and technique of byproduct utilization. In China, private enterprises mainly adopt the technology of acidic and alkaline catalysts to produce biodiesel which could result in environmental pollution [34,35]. However, mass industrial application of biocatalyst which can reduce production cost has not commenced in China [35,36]. There is no specialized technological standard with regard to jatropha biodiesel refining and processing which has been established by government in China. Although the national standard for the BD100 (pure biodiesel) has been set and implemented in China [37–39], the establishment for standards of BD5 (5% biodiesel blends with 95% diesel) and BD20 (20% biodiesel blends with 80% diesel) are still under way [38]. Furthermore, the implementation of BD100 in China is not obligatory [39]. Besides, the technique for deep exploitation of byproduct or residue is far from commercial use [40].

#### 3.1.1.5. *Economical issues.*

- Comparative benefit for planting jatropha.

Luo and Zhang [29] indicate that the comparative benefit for planting jatropha is lower than that for planting cash crops and fruits in Panzhihua (see Tables A.2 and A.3), i.e. 4875 RMB/ha lower than tobacco, 10,575 RMB/ha lower than wheat, 42,525 RMB/ha lower than loquat, 17,625 RMB/ha lower than sugarcane and 53,775 RMB/ha lower than mango. However, if the unit seed yield of jatropha can reach 10.5 tonnes/ha, the comparative benefit will be higher than wheat and will be more acceptable by farmers [29]. They further indicate that the comparative benefit is subjected to seed yield, seed oil content, biodiesel refining and processing technology, international price of crude oil and cost for picking seeds of jatropha [29]. Followed as this study, Zhang et al. [23] also review and indicate the comparative benefit for cultivating jatropha is low because of poor seed yield.

- Cost and benefit for jatropha biodiesel production.

The components of direct production cost for jatropha biodiesel are mainly consisted by planting cost as well as refining and processing cost. Zheng and Wang [32] conduct a rough cost-benefit analysis on jatropha biodiesel production in Panzhihua, which suggests that the production costs outweigh the benefits. Weyerhaeuser et al. [5], Lu and Wang [22], Fei et al. [28], Wang [33] show their worry about high production cost for current biodiesel production in China. Moreover, according to Weyerhaeuser et al. [5], the mean seed production costs for jatropha could reach 6750 RMB/tonne and the processing costs is 1000 RMB/tonne. Therefore, based on Weyerhaeuser et al. [5], it is clear that 1 tonne jatropha biodiesel production can cause economic loss of 2750 RMB when the biodiesel price is 5000 RMB/tonne.

3.1.1.6. *Marketing issues.* Biodiesel in China is mainly produced by private enterprises rather than by state-owned enterprises like China National Petroleum Corporation (CNPC), China National Offshore Oil Corporation (CNOOC) as well as China Petrochemical Corporation (Sinopec). Due to lack of product quality standard and poor product quality, biodiesel produced by private enterprises has not entered into the marketing system of state-owned enterprise which dominates the energy supply in China [41]. Actually, jatropha biodiesel markets will be controlled by CNPC, CNOOC and Sinopec when jatropha biodiesel is used for diesel blends [5]. Weyerhaeuser et al. [5] also indicate that the production costs for jatropha biodiesel can reach 13,000 RMB/tonne which is obviously higher than ethanol and diesel. Hence, jatropha biodiesel has poorer market competitiveness than ethanol and diesel when they have minor price discrepancies [5]. Moreover, the profit of biodiesel is shaped by the price of crude oil to a large extent [33].

3.1.1.7. *Subsidy issues.* In fact, current subsidies for jatropha planting and jatropha biodiesel production in China are lower than those for ethanol production [5]. Wang [33] indicates that the current subsidy within government' s policy in China is rather weak, therefore it is difficult to enable the benefit of woody seed biodiesel to outweigh its production cost. Although jatropha biodiesel production costs are higher than ethanol, central government only subsidize 6000 RMB/ha for jatropha planting. Actually, farmers seldom receive planting subsidy because jatropha cultivation is mainly conducted by enterprises. Even so, most of enterprises only receive half amount of planting subsidy, i.e. 3000 RMB/ha. Moreover, subsidies provided for refining have not implemented at present. Due to higher production costs and obviously lower subsidy level, enterprises have poor motivation to implement their development plans for jatropha biodiesel.

### 3.1.2. *Issues on the industry of India, Tanzania and Kenya from international journals*

Industrial projects of jatropha biodiesel are mainly implemented in developing or under-developed countries in Asia and Africa. In fact, the industry of these countries is still in infancy [42], though the time for commencing the construction in each nation varies widely. Indeed, massive commercial jatropha biodiesel production and marketing has not been actualized till date owing to varieties of issues. However, very few papers specially or directly focus on problems or risks of jatropha biodiesel industry in a country. Because the related literature is largely absent, therefore, we do select relatively in-depth studies on the industry of India, Tanzania and Kenya.

Although India has drafted ambitious plan for jatropha biodiesel industry within its national biodiesel mission [43], the development of this industry is confronting many obstacles (see Table 1). Actually, mass industrial production for jatropha biodiesel has not conducted in India [44,45]. Simultaneously, as African countries, the industry of Tanzania and Kenya also has received much attention. Wiskerke et al. [47] raise the issues through a cost/benefit analysis of jatropha oil production in a sample region of Tanzania. Eijck and Romijn [48] also indicate the problems of Tanzania by the method of strategic niche management. As summarized in Table 2, we classify the mentioned problems of jatropha biodiesel industry in Tanzania. The construction of jatropha biodiesel industry in Kenya has been conducted in 2005 [49], however, large-scale industrial production for jatropha biodiesel has not started due to many issues (see Table 3). Therefore, according to Tables 1–3, we can conclude that issues of jatropha biodiesel industry in India, Tanzania and Kenya are rather similar, they all face common problems, i.e. cultivation issues, economic issues, technical issues, research issues, land issues, marketing issues and subsidy issues.

## 3.2. *Current status of risk management for jatropha biodiesel industry*

Generally, complete procedures of risk management involve risk identification, risk assessment, risk response, risk monitoring

**Table 1**
The mentioned problems on jatropha biodiesel industry of India.

| Problems classification | Problems subdivision | Source |
|---|---|---|
| Land issues | Less availability of land for jatropha cultivation | [43,44] |
| Basic research issues | Low seed yield and low oil content | [42] |
| Limited refining capacity | Lack of refining and processing infrastructure | [45] |
| Cultivation issues | Small-scale plantation | [45] |
| | Poor planting motivation from the farmers | [45] |
| Biodiesel production technical issues | Poor utilization for by-product glycerol | [45] |
| | Absence of appropriate technologies suited to different scales | [44] |
| | Lack of effective means to monitor biodiesel product quality | [44] |
| Economical issues | Higher production cost compared to that of petrodiesel | [46] |
| | Absence of easy loan for oil extraction and collection facility | [45] |
| Marketing issues | Lack of marketing system for jatropha cultivation | [42] |
| | Unpredictable seed prices | [44] |
| | Absence of large-scale biodiesel production and marketing | [44] |
| Subsidy issues | Poor subsidies to farmers for jatropha cultivation | [42] |
| | Poor price subsidy to guarantee minimum income for farmers | [42] |

[50]. Actually, specialized risk studies on jatropha biodiesel industry are very limited. Further, very few studies on the risk of this industry cover all steps of risk management. Brittaine and Lutaladio [51] identify three groups of risks, which are classified as economic risks, environmental risks and social risks. Biswas et al. [44] point out that seed-yield risk, seed-price risk, planting-cost risk and ecological risk are the hurdles for massive cultivation of jatropha. Wang [52] establishes a risk indexes system for exploitation evaluation of woody oil resources, however, this risk indexes system is not well suited to jatropha biodiesel industry. Furthermore, Wang [52] also conducts a risk analysis of an investment project for jatropha biodiesel industry in the region of the Three Geoges in Chongqing, however, this risk analysis tends to demonstrate the financial, social and ecological feasibility for applying for national investment and government subsidy.

**Table 2**
The mentioned problems on jatropha biodiesel industry of Tanzania.

| Problems classification | Problems subdivision | Source |
|---|---|---|
| Cultivation issues | Jatropha planting enhances competition with livestock | [47] |
| | Enhances competition with planting food crops | [47] |
| Economic issues | Low economic benefit of seed production for farmers | [47] |
| | Production cost of seeds outweigh its selling price | [47] |
| | High labor cost for jatropha oil production | [47] |
| | Poor profitability for jatropha oil production | [47] |
| | Less economically feasible of jatropha oil for family cooking | [47] |
| Technical issues | Lack of cultivation technologies for farmers | [48] |
| | Poor research on cultivation techniques | [48] |
| Biodiesel production issues | Decentralized biodiesel production | [47] |
| | Lack of pressing machines suited to hard seeds of jatropha | [48] |
| Marketing issues | Higher price of jatropha biodiesel than that of diesel | [48] |
| | Higher price of jatropha soap than that of ordinary soap | [48] |
| | Insufficient use of seedcake and jatropha oil by farmers | [48] |
| Subsidy issues | Lack of subsidy to jatropha cultivation for farmers | [47] |
| | Lack of financial support for oil refining and processing | [48] |
| Other issues | Contract cancelled by Non-Government Organizations (NGO) for paying for seeds providers | [48] |
| | High expectation towards seed yield and seed price | [48] |

**Table 3**
The mentioned problems on jatropha biodiesel industry of Kenya.

| Problems classification | Problems subdivision |
|---|---|
| Cultivation issues | Variation of seeds yields due to different conditions |
| | Massive monoculture results in ecosystem deterioration |
| | Low quality of jatropha seedlings for massive cultivation |
| | Enhance competition with the plantation of food crops |
| | Canola could be a more promising feedstock than jatropha |
| | Less motivation for the farmers to conduct cultivation due to poor income |
| Research issues | Poor research on seeds yields, seed oil content under different conditions |
| Land issues | Limited land of the farmers for jatropha plantation |
| Biodiesel production issues | Lack of commercial jatropha production |
| | Lack of small pressing equipments in local market |
| | Lack of transesterification for jatropha oil |
| Marketing issues | Uncertain status of market for selling seeds |
| Subsidy issues | Lack of subsidy for buying the expellers |

*Source*: [49].

Particularly, Liu et al. [10] (author's previous study) analyze the risk occurrence mechanism of jatropha biodiesel industry within the philosophical scope of contingency, necessity, complexity and epistemology. Consequently, Liu et al. [10] identify and classify the industrial risks of Panzhihua into two groups, which could be named as risks of the contingency and risks of necessity. However, this study does not deal with other procedures of risk management. Therefore, we may conclude that current risk studies of jatropha biodiesel industry mainly focus on risk identification, however, the stages of risk analysis, risk response, risk monitoring have not been involved. In other words, comprehensive and complete application of risk management has not commenced till date.

## 4. Experimental methods

As Hertz and Thomas [53] indicated, risk could be described as "a barrier to success". According to Nieto-Morote and Ruz-Vila [54], risks are deeply embedded in every procedure for implementing a plan or fulfilling a target, therefore, it is impossible to clear them out completely. However, to a large extent, we can reduce their negative impacts by the tool of risk management. Till date, risk management has many applications to projects management, military affairs, financing activities and other scopes. Consequently, the extension of risk management to jatropha biodiesel industry can help us to establish an effective and systematic mechanism for risk response and risk monitoring, which could maintain long-term viability of this industry.

### 4.1. Risk identification

Risk identification refers to clarify and classify underlying risks [54] which could impose detrimental influence upon jatropha biodiesel industry. Actually, risk identification underpin the foundation for the rest stages of risk management [55]. In order to have

a complete and in-depth risk identification, we conduct it by the method of iteration [56] as shown in Appendix D.

### 4.2. Risk assessment

Risk assessment is the core of risk management. In this stage, the numerical value of each identified risk could be measured [54,57]. Accordingly, the ranking order for risk response could be determined based on the numerical value of each risk. The methodology of risk assessment refers to how to quantify the risk value and how to determine the priority for risk response.

#### 4.2.1. The method to quantify risk value

Suppose a risk has three attributes, i.e. the probability of risk occurrence, the severity of risk loss and the degree of difficulty for risk control [54,57]. Therefore, we could determine risk value by quantifying the three attributes (see Appendix E).

#### 4.2.2. The method to determine the priority for risk response

Due to limited resources [57], it is impossible to deal with all identified risks of jatropha biodiesel industry in Panzhihua simultaneously. Therefore, it is necessary to determine the priority for risk response in order to have an intensive and effective risk management. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can determine the alternative which is in the farthest distance from the positive ideal solution and closest from the negative ideal solution [61]. Driven by this reason, the method of TOPSIS proposed by Hwang and Yoon [61] is adopted in this paper. Essentially, by TOPSIS method, we can determine and then deal with the identified risks of which is in the farthest distance from the positive ideal solution [57,61]. According to Hwang and Yoon [61], Li [57], the TOPSIS method can be employed as shown in Appendix F.

### 4.3. Data collection

The data for the determination of primitive values for risk indicators could be seen in Appendix A. Because the data with respect to jatropha biodiesel industry of Panzhihua is largely absent and is rather difficult to collect, therefore most of the data are largely from domestic references and partly by our survey and estimation. The determination for the expected values of risk indicators could be found in Appendix B. The determination for the primitive risk values of risk indicators can be seen in Appendix C.

## 5. Results and discussion

### 5.1. The results of risk identification

According to the method of risk identification, all the identified risks have been classified as four categories: jatropha cultivation risks, jatropha biodiesel production risks, marketing risks, policy and subsidy risks. Actually, it is impossible and unnecessary to identify all the potential risk factors because the impact of some risk factors could be ignored. Moreover, the cost for risk management would be high if take all underlying risks into account. Therefore, according to the above risk categories, we identify 14 risk factors which may have critical influence upon the industry in Panzhihua. Consequently, a risk indicators system is finally established (see Table 6).

As shown in Table 6, the identified risks are largely similar to those mentioned problems and risk factors in the papers which have been reviewed in previous sections of this article. Particularly, Liu et al. [10] also indicated risk indicators C1, C3, C4, C5, C6, C7, C8, C9 in their earlier study on the risk occurrence mechanism of jatropha biodiesel industry in Panzhihua. Followed as further study to Liu et al. [10], the results of risk identification in this paper have confirmed the findings in the study of Liu et al. [10].

**Table 4**
Local experts for questionnaire survey.

| Local experts from different stakeholders | Number of the local experts |
|---|---|
| Panzhihua Forestry Bureau | 6 |
| The Forestry Bureau of Renhe District | 6 |
| The Forestry Bureau of Yanbian County | 4 |
| Panzhihua College | 3 |
| The Agricultural and Forestry Research Institution of Panzhihua | 6 |
| The Biofuel Office of Panzhihua | 5 |
| The Forestry Extention Station of Panzhihua | 2 |
| The Forestry Station of Zongfa Town | 2 |
| The People's Government of Tongzilin | 2 |
| The Farmers who plant jatropha[a] | 8 |
| The staff (farmers) of jatropha planting base | 3 |
| The contractors who foster and sell jatropha seedlings[b] | 3 |

[a] According to our survey, very few farmers plant jatropha in Panzhihua. Therefore, it is rather difficult for us to find them.

[b] The staff are from nearby regions not local resident. Most of them are Yi minority group (in Chinese, we call Yizhu). Because local farmers think it is not profitable for planting jatropha, so very few people are employed by the planting base except poor farmers like the Yi minority.

### 5.2. The results of risk assessment

#### 5.2.1. The results of quantifying risk value

*5.2.1.1. Probability quantification.* According to the method of risk identification (especially based on iteration 3 and 4), the identified risks in Table 6 actually have occurred in Panzhihua. Therefore, according to Table 5 [58,59], the probabilities of occurrence for all the identified risks could Table 6 be rated as "the most possible to happen" in future. Consequently, as indicated in Table 7, the value of probability has been quantified.

*5.2.1.2. Severity quantification.* According to formula (1) [60], formulas (4) and (5) [57,60], severity quantification has been calculated as shown in Table 8.

*5.2.1.3. Quantify the possibility for risk control.* According to formula (2), the possibility for risk control could be determined as indicated in Table 9. Therefore, we can get the quantification results for the three attributes of each risk indicator based on Tables 7–9. The results are shown in Table 10.

#### 5.2.2. The results of determining the priority for risk response

*5.2.2.1. Determine the relative weights for the three attributes of each risk indicator.* The relative weights of the three attributes for each risk indicator are determined by linguistic variables, which are denoted in Table 11. According to Table 11 and our project members' survey and evaluation, the relative weights could be determined as indicated in Table 12.

**Table 5**
The approach of probability quantification.

| The qualitative description of probability | Predetermined value |
|---|---|
| Impossible to occur | 0.10 |
| Less possible to occur | 0.30 |
| Possible to occur | 0.50 |
| More possible to occur | 0.70 |
| The most possible (certain) to occur | 0.90 |

*Source*: [58,59].

**Table 6**
The risk indicators system for risk assessment on jatropha biodiesel industry in Panzhihua.

| Risks categories | Risk no. | Risk indicators |
|---|---|---|
| Jatropha cultivation | C1 | Low seed yield |
| | C2 | Low oil content of kernel |
| | C3 | Insect pests and diseases |
| | C4 | Low comparative benefits for planting jatropha |
| | C5 | Poor implementation for the plans set for jatropha cultivation |
| | C6 | Insufficient available lands for fulfilling cultivation plan |
| Biodiesel production | C7 | Poor implementation for the plans set for establishing jatropha biodiesel refining capacity |
| | C8 | Low profitability for jatropha biodiesel production |
| Marketing | C9 | No local gas station selling jatropha biodiesel |
| | C10 | Low comparative price of biodiesel versus diesel |
| | C11 | High popularity rate for the use of solar energy |
| Policy and subsidy | C12 | Insufficient subsidy for farmers to conduct cultivation |
| | C13 | Insufficient subsidy for conducting biodiesel production |
| | C14 | Insufficient subsidy for the enterprise to conduct cultivation |

**Table 7**
Probability quantification for all the indentified risks.

| Risks categories | Risk no. | The value of probability ($P_{ci}$) |
|---|---|---|
| | C1 | 0.9000 |
| | C2 | 0.9000 |
| | C3 | 0.9000 |
| Jatropha cultivation | C4 | 0.9000 |
| | C5 | 0.9000 |
| | C6 | 0.9000 |
| Biodiesel production | C7 | 0.9000 |
| | C8 | 0.9000 |
| | C9 | 0.9000 |
| Marketing | C10 | 0.9000 |
| | C11 | 0.9000 |
| | C12 | 0.9000 |
| Policy and subsidy | C13 | 0.9000 |
| | C14 | 0.9000 |

*5.2.2.2. Determine the positive and negative ideal solutions.* According to formulas (8) and (9) [57,61], the positive ideal solution and negative ideal solution could be determined as the followings:

$$Q^+ = \{0.9000, 1.0000, 0.6143\} = \max\{P_{Ci}, W_{Ci}, D_{Ci}\}$$

$$Q^- = \{0.9000, 0.4286, 0.1000\} = \min\{P_{Ci}, W_{Ci}, D_{Ci}\}$$

**Table 8**
Normalization for the primitive risk values of severity.

| Risk indicators | Normalization results ($W_{ci}$) |
|---|---|
| C1 | 1.0000 |
| C2 | 0.4286 |
| C3 | 1.0000 |
| C4 | 0.5077 |
| C5 | 0.9695 |
| C6 | 0.6256 |
| C7 | 1.0000 |
| C8 | 1.0000 |
| C9 | 1.0000 |
| C10 | 1.0000 |
| C11 | 0.6000 |
| C12 | 1.0000 |
| C13 | 1.0000 |
| C14 | 0.5000 |

**Table 9**
Quantify the possibility for risk control.

| Risk indicators | Quantification results ($D_{ci}$) |
|---|---|
| C1 | 0.1000 |
| C2 | 0.6143 |
| C3 | 0.1000 |
| C4 | 0.5431 |
| C5 | 0.1275 |
| C6 | 0.4370 |
| C7 | 0.1000 |
| C8 | 0.1000 |
| C9 | 0.1000 |
| C10 | 0.1000 |
| C11 | 0.4600 |
| C12 | 0.1000 |
| C13 | 0.1000 |
| C14 | 0.5500 |

**Table 10**
Quantification for the three attributes of each risk indicator.

| Risk indicators | Probability ($P_{ci}$) | Severity ($W_{ci}$) | The possibility for risk control ($D_{ci}$) |
|---|---|---|---|
| C1 | 0.9000 | 1.0000 | 0.1000 |
| C2 | 0.9000 | 0.4286 | 0.6143 |
| C3 | 0.9000 | 1.0000 | 0.1000 |
| C4 | 0.9000 | 0.5077 | 0.5431 |
| C5 | 0.9000 | 0.9695 | 0.1275 |
| C6 | 0.9000 | 0.6256 | 0.4370 |
| C7 | 0.9000 | 1.0000 | 0.1000 |
| C8 | 0.9000 | 1.0000 | 0.1000 |
| C9 | 0.9000 | 1.0000 | 0.1000 |
| C10 | 0.9000 | 1.0000 | 0.1000 |
| C11 | 0.9000 | 0.6000 | 0.4600 |
| C12 | 0.9000 | 1.0000 | 0.1000 |
| C13 | 0.9000 | 1.0000 | 0.1000 |
| C14 | 0.9000 | 0.5000 | 0.5500 |

**Table 11**
The linguistic variables for the relative weights of each attribute.

| Linguistic variables | Predetermined values |
|---|---|
| Important | 0.20 |
| Very important | 0.40 |
| More important | 0.60 |
| The most important | 0.80 |

*5.2.2.3. Calculate the Euclidean distances of each risk from the ideal solutions.* The Euclidean distances of each identified risk from the positive and negative ideal solutions could be calculated by formulas (10) and (11) [57,61]. The results are shown in Table 13.

*5.2.2.4. Calculate the relative closeness to the positive ideal solution $Q^+$.* According to formula (12) [57,61], the relative closeness of each identified risk to the positive ideal solution $Q^+$ could be calculated as shown in Table 14.

*5.2.2.5. Determine the priority for risk response.* According to the relative closeness to the positive ideal solution $Q^+$, the priority for risk response could be ranked as indicated in Table 15.

**Table 12**
The relative weights for each attribute.

| Attribute | Linguistic description | Predetermined values |
|---|---|---|
| Probability | Important | 0.20 |
| Severity | Very important | 0.40 |
| The possibility for risk control | Very important | 0.40 |

**Table 13**
Calculation for the Euclidean distances.

| Risk indicators | $L^+$ | $L^-$ |
|---|---|---|
| C1 | 0.2057 | 0.2286 |
| C2 | 0.2286 | 0.2057 |
| C3 | 0.2057 | 0.2286 |
| C4 | 0.1989 | 0.1800 |
| C5 | 0.1951 | 0.2166 |
| C6 | 0.1657 | 0.1561 |
| C7 | 0.2057 | 0.2286 |
| C8 | 0.2057 | 0.2286 |
| C9 | 0.2057 | 0.2286 |
| C10 | 0.2057 | 0.2286 |
| C11 | 0.1715 | 0.1595 |
| C12 | 0.2057 | 0.2286 |
| C13 | 0.2057 | 0.2286 |
| C14 | 0.2016 | 0.1823 |

**Table 14**
Calculation for the relative closeness to the positive ideal solution.

| Risk indicators | Relative closeness ($N_i$) | Risk indicators | Relative closeness ($N_i$) |
|---|---|---|---|
| C1 | 0.5264 | C8 | 0.5264 |
| C2 | 0.4736 | C9 | 0.5264 |
| C3 | 0.5264 | C10 | 0.5264 |
| C4 | 0.4751 | C11 | 0.4819 |
| C5 | 0.5261 | C12 | 0.5264 |
| C6 | 0.4851 | C13 | 0.5264 |
| C7 | 0.5264 | C14 | 0.4749 |

**Table 15**
Determine the priority for risk response.

| Risk indicators | Relative closeness ($N_i$) | Ranking order |
|---|---|---|
| C1 | 0.5264 | 1 |
| C3 | 0.5264 | 1 |
| C7 | 0.5264 | 1 |
| C8 | 0.5264 | 1 |
| C9 | 0.5264 | 1 |
| C10 | 0.5264 | 1 |
| C12 | 0.5264 | 1 |
| C13 | 0.5264 | 1 |
| C5 | 0.5261 | 9 |
| C6 | 0.4851 | 10 |
| C11 | 0.4819 | 11 |
| C4 | 0.4751 | 12 |
| C14 | 0.4749 | 13 |
| C2 | 0.4736 | 14 |

### 5.3. Risk response

The objective of risk response is to take effective measures to reduce the negative impacts of the risks [58]. Generally, risk response includes risk alleviation (reduction), tolerate, transfer and avoidance [58]. Because all the identified risks have high probabilities to occur (they actually happen at present and will be very likely to take place in the future) and have critical influences upon the jatropha biodiesel industry of Panzhihua, so we can only minimize the negative impacts to a certain extent. Therefore, risk alleviation is feasible and applicable to respond to all the identified risks. According to Table 15, the priority for risk response has been determined. Risk indicators C1, C3, C7, C8, C9, C10, C12, C13 are ranked as the first grade to take immediate measures of risk reduction owing to their key importance in shaping the industry in Panzhihua. Table 16 shows the actions to reduce the magnitude of the first treated risks and other lower grade risks.

### 5.4. Risk monitoring

According to the results of risk assessment, the identified risks have imposed critical influences upon the jatropha biodiesel industry in Panzhihua. In other words, the long-term viability of this industry has been seriously threatened. Therefore, it is rather urgent to raise the awareness of risk monitoring. The objective of risk monitoring for jatropha biodiesel industry is to establish a constant and continuous risk monitoring mechanism which involves frequent risk identification, constant risk assessment and immediate risk response. This mechanism should be adaptable and flexible to different developing stages of jatropha biodiesel industry in Panzhihua. Therefore, actually, risk monitoring is a very complex system which integrates different risk management actions, different stakeholders, different departments of local governments, different monitoring technologies and different routes of risk reporting and feedback. Although the People's Government of Panzhihua has established a special bioenergy administration office which is a subordinate branch of the Panzhihua Forestry Bureau, it has very limited influence in managing and monitoring the jatropha biodiesel industry of Panzhihua. Therefore, in order to facilitate the risk management, Fig. 2 shows the outline of establishing the risk monitoring system for jatropha biodiesel industry in Panzhihua.

**Table 16**
The measures for risk reduction for jatropha biodiesel industry in Panzhihua.

| Risk indicators | Treating grade | The measures for risk reduction |
|---|---|---|
| C1 | 1 | • Variety breeding<br>• Improve the amounts of female flowers of jatropha<br>• Comprehensive and complete planting techniques research and application, including seeds selection procedures, seedlings, fostering measures, height-control methods, field management measures. |
| C3 | 1 | • Improve the biodiversity of jatropha based ecosystem, attempt to establish jatropha-Agave sisalana Perrine-Eucalyptus community, jatropha-cash crops community, jatropha-grass community. |
| C7 | 1 | • Lower the refining capacity of jatropha biodiesel, enhance the industrial demonstration effects to investors, governments and farmers. |
| C8 | 1 | • Adopt biocatalyst to produce jatropha biodiesel quickly. |
| C9 | 1 | • Obligatory polices issued by central government to force the state-owned energy enterprises to purchase the jatropha biodiesel and sold within their domestic marketing system. |
| C10 | 1 | • Government must establish protective price mechanism for jatropha biodiesel to maintain its minimum profit. |
| C12 | 1 | • Government and state-owned enterprises must establish minimum subsidy mechanism to make the benefits for planting jatropha outweigh its costs. |
| C13 | 1 | • Government must establish flexible subsidy and tax systems with respect to the fluctuations of diesel and biodiesel prices, seed prices, prices of biodiesel production materials and inflation level. |
| C5 | 2 | • Lower the scale of jatropha cultivation, improve the seed yield per unit. |
| C6 | 3 | • Re-set the cultivation plan, enhance the field management level for the exiting planting base. |
| C11 | 4 | • Encourage local enterprises and transportations to use jatropha biodiesel at lower prices. Encourage local farmers to use jatropha oil cake as fertilizer. |
| C4 | 5 | • Cultivate with other cash crops. |
| C14 | 6 | • Enhance the field management, build flexible subsidy systems |
| C2 | 7 | • Variety breeding |

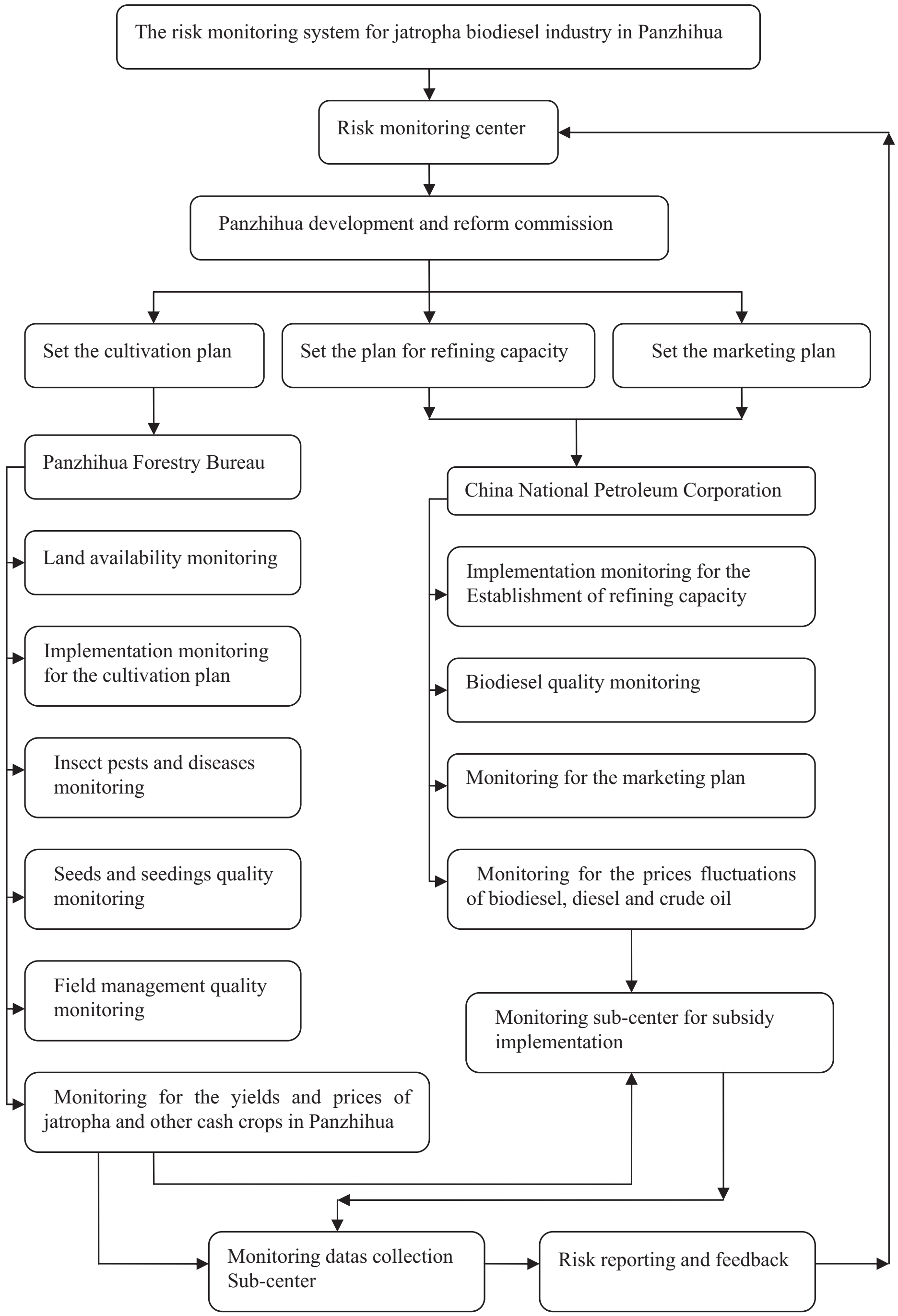


**Fig. 2.** The risk monitoring system for jatropha biodiesel industry in Panzhihua.

### 5.5. Discussion

This study has transplanted the ideas of risk management to the regulation for jatropha biodiesel industry of Panzhihua, covering all the procedures of risk management with respect to risk identification, risk assessment, risk response and risk monitoring. The results of this paper show that the hurdles for the development of jatropha biodiesel industry in Panzhihua are similar to those of India, Tanzania and Kenya. In other words, the jatropha biodiesel industry in these countries are still in infancy [42] and they do face common risks. Actually, all the identified risks in this paper have very high probabilities to occur in the future and they have critical influences upon this industry. Largely, their negative impacts could not be eliminated completely. Therefore, it is impossible and difficult to tolerate, transfer, avoid these risks. What we can do is to minimize the negative impacts to a certain extent. From this view, risk reduction is an effective mean. Actually, it is a very long way to cover before the jatropha biodiesel scenario to be materialized in Panzhihua. The urgent tasks for the local governments in Panzhihua are just to maintain but adjust their ambitious plans, enhance the demonstration effects of industrial projects at an appropriate and economic scale.

However, jatropha is definitely not the alternative which may embarrass the decisions and desires of local governments in

Panzhihua. Actually, jatropha remains to be an effective plant to reclaim the damaged ecosystem of the dry-hot river valley in Panzhihua and to be a promising feedstock for biodiesel to reduce local energy dependence on crude oil. More importantly, the Chinese government has conducted a reform which can convert the collectively owned forest land to privately owned. Under this policy, the local farmers could improve their incomes by cultivation of jatropha. They also could rent their forest lands or sell the utilization rights to governments or enterprises. Therefore, in order to maintain long-term viability of this industry, local governments should immediately establish a robust and feasible policies-supporting system to foster the vertical integration from upstream cultivation to downstream processing and marketing and to ensure the minimum profits for all stakeholders by a flexible subsidy system.

The main objective of this paper is to tentatively and initially apply the theories and methodologies of risk management to the regulation for jatropha biodiesel industry. Actually, according to our survey, the results of risk identification and assessment in this study are in accordance with current situation of jatropha biodiesel industry in Panzhihua. In other words, it is proved that the extension of risk management to jatropha biodiesel industry has been applicable. However, There are three important limitations of this paper which need to be concerned with. First, the jatropha cultivation plan in Panzhihua have conducted in 2006, so the plants of jatropha have not entered into mature period till date and the unit seed yield for plantation base in Panzhihua is extremely low. Furthermore, no refining capacity for jatropha biodiesel in Panzhihua has been materialized at present. Therefore, it is rather difficult to collect these data with respect to seed yield, biodiesel price, processing cost and profit. Actually, most of the data are largely from domestic references and partly by our estimation.

Second, the risk assessment in this paper does not take into account the international and domestic prices fluctuation of crude oil, diesel, gasoline, biodiesel and other forms of renewable energy. Therefore, it is rather complex and difficult to evaluate the impacts of the prices fluctuation risk imposing on the local jatropha biodiesel industry. Indeed, it needs a rigorous and special study in the future.

Third, due to largely absence of related data, the cost and benefit analyses with regard to the planting of jatropha and other cash crops, jatropha biodiesel production are very rough. However, unlike the detailed financial analysis, the primary objective of this study is to reveal the magnitude of each identified risks and to determine their priorities for risk response. From this perspective, the research process of this paper is reasonably simplified by TOPSIS method and more importantly, the results are also proved to be reasonable.

## 6. Conclusion

As one of the most important regions selected for jatropha biodiesel industry in China, Panzhihua has received very high and optimistic expectations from the governments, enterprises and experts. The outlook of this industry in their eyes could be described as pillar industry for the local economy. However, this study suggests that jatropha seems to have slight impacts on changing local scenarios of energy, economy and ecology. Eventually, the results in this study indicate that the industry in Panzhihua has been seriously threatened by various kinds of risks, such as land risks, marketing risks, economic risks and subsidy risks. Moreover, the findings of this paper tell the decision-makers of different stakeholders to raise the awareness of risk management for jatropha biodiesel industry in Panzhihua and to highlight the urgency to establish a robust, sensitive and frequent risk monitoring mechanism. The risk assessment method of TOPSIS in this study has determined the priorities for risk response. It is suggested that risk indicators of C1 (low seed yield), C3 (insect pests and diseases), C7 (poor implementation for the plans set for establishing jatropha biodiesel refining capacity), C8 (low profitability for jatropha biodiesel production), C9 (no local gas station selling jatropha biodiesel), C10 (low comparative price of biodiesel versus diesel), C12 (insufficient subsidy for farmers to conduct cultivation), C13 (insufficient subsidy for conducting biodiesel production) have been ranked as the first status to take immediate measures for risk response. More importantly, this paper also tells the decision-makers to establish a risk monitoring system and take necessary measures for risk reduction.

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## Appendix A. Data collection for the primitive values of risk indicators

Tables A.1–A.9

**Table A.1**
The primitive values of risk indicators.

| Risk indicators | Primitive values ($Q_{ci}$) | Unit | Source |
|---|---|---|---|
| C1 | 2.25 | Tonne/ha | Survey and estimate[a] |
| C2 | 56.4%[b] | | Liao [62] |
| C3 | 24 | Species | Yu et al. [26] |
| C4 | −29,700[c] | Yuan/ha | Luo and Zhang [29] |
| C5 | 12,000 | Hectare | See Table A.4 |
| C6 | −246,067 | Hectare | See Tables A.4–A.6 |
| C7 | 0 | Tonne | Survey |
| C8 | −2750 | RMB/tonne | See Table A.7 |
| C9 | 0 | | Survey |
| C10 | −819 | RMB/tonne | See Tables A.7 and A.8 |
| C11 | 40% | | Chen [63] |
| C12 | 0 | RMB/ha | Survey |
| C13 | 0 | RMB/tonne | Survey |
| C14 | 3000 | RMB/ha | Provided by the PFB |

[a] The construction of jatropha plantation base established by the CNPC and NFB (The National Forestry Bureau) in Panzhihua has started since 2006 [64]. Therefore, jatropha has not entered into high-yield period. Due to this reason, we have to use the seed yield of wild mature jatropha as a source for the estimation. According to the data provided by the PFB (The Panzhihua Forestry Bureau), the average tree density for jatropha cultivation is 1500 trees per hectare [64].
[b] See Table A.9.
[c] See Tables A.2 and A.3.

**Table A.2**
The cost and benefit analysis for planting jatropha and other cash crops in Panzhihua (2007).

| Cash crops | Planting cost (RMB/ha) | Yield (tonne/ha) | Price (RMB/tonne) | Output value (RMB/ha) | Benefits (RMB/ha) |
|---|---|---|---|---|---|
| Mango | 7500–12,000 | 15–22.5 | 3000–4000 | 45,000–90,000 | 37,500–78,000 |
| Sugarcane | 1200–1500 | 90 | 210–300 | 18,900–27,000 | 17,700–25,500 |
| Loquat | 12,000–15,000 | 7.5–11.25 | 4000–8000 | 30,000–90,000 | 18,000–75,000 |
| Tobacco | 4200 | 1.875 | 6960 | 13,050 | 8850 |
| Jatropha | 450–600 | 2.25 | 2000 | 4500 | 3900–4050 |

*Source*: Luo and Zhang [29].

**Table A.3**
The comparative benefits for planting jatropha.

| Crops | Mean benefits[a] (RMB/ha) | The comparative benefits for planting jatropha[b] (RMB/ha) | Mean comparative benefit for planting jatropha[c] (RMB/ha) |
|---|---|---|---|
| Mango | 57,750 | −53,775 | −29,700 |
| Sugarcane | 21,600 | −17,625 | |
| Loquat | 46,500 | −42,525 | |
| Tobacco | 8850 | −4875 | |
| Jatropha | 3975 | 0 | |

[a,b,c] The calculations are based on the data of Luo and Zhang [29].

**Table A.4**
The jatropha biodiesel projects of different enterprises and their implementation status in Panzhihua.[a]

| Enterprises[b] | Plans set for cultivation (ha) | Fulfilled plans for cultivation (ha) | Targets set for establishing jatropha biodiesel refining capacity (tonne/year) | Fulfilled plans for establishing refining capacity (tonne/year) |
|---|---|---|---|---|
| China National Petroleum Corporation | 66,667 | 10,667[c] | 100,000 | 0 |
| China National Offshore Oil Corporation | 33,333 | 0 | 100,000 | 0 |
| Sinopec Group | 26,667 | 0 | 100,000 | 0 |
| Spain Beck Biofuel Corporation | 200,000 | 1333 | 400,000 | 0 |
| British Sunlight Technology Group | 66,667 | 0 | Planned to establish | 0 |

*Source*: [13], Wen [65].
[a] As a proof of author's earlier study [10], this table firstly has been reported at a Chinese journal of Forestry Economics.
[b] According to our survey and personal communication with the officials of Panzhihua Forestry Bureau, all the projects belonging to different enterprises have been ceased due to many reasons.
[c] According to our survey, no cultivation coverage work has been done in 2009 and 2010.

**Table A.5**
The categories of forestry lands in Panzhihua.

| The categories of forestry lands in Panzhihua | Coverage (ha) |
|---|---|
| Forest land | 407,067 |
| Shrub land | 73,000 |
| Sparse forest land | 3267 |
| Immature forest land (by afforestation) | 7733 |
| Barren land | 63,267 |

*Source*: [64].

**Table A.6**
Available lands for fulfilling jatropha cultivation plans in Panzhihua.

| Available lands for fulfilling cultivation plans | Coverage (ha) | Total coverage plans set by different corporations (ha) |
|---|---|---|
| Shrub land | 73,000 | 393,334 |
| Sparse forest land | 3267 | |
| Immature forest land | 7733 | |
| Barren land | 63,267 | |
| Total | 147,267 | |
| Lack of available land | −246,067 | |

*Source*: [13,64,65].

**Table A.7**
The benefit calculation for jatropha biodiesel production (2007).

| Parameters | Value | Unit |
|---|---|---|
| Seed production costs | 6750 | RMB/tonne |
| Processing costs | 1000 | RMB/tonne |
| Biodiesel price (by survey and estimation) | 5000 | RMB/tonne |
| Benefit | −2750 | RMB/tonne |

*Source*: Weyerhaeuser et al. [5].

**Table A.8**
The 0# diesel price in Panzhihua in 2007.

| Month | Price | Unit |
|---|---|---|
| January | 4.77 | RMB/l |
| February | 4.82 | RMB/l |
| March | 4.82 | RMB/l |
| April | 4.82 | RMB/l |
| May | 4.82 | RMB/l |
| June | 4.82 | RMB/l |
| July | 4.82 | RMB/l |
| August | 4.82 | RMB/l |
| September | 4.82 | RMB/l |
| October | 4.82 | RMB/l |
| November | 5.28 | RMB/l |
| December | 5.28 | RMB/l |
| Mean | 4.89 | RMB/l |
| | 5819 | RMB/tonne |

*Source*: [66].

**Table A.9**
The oil content of kernel of jatropha seeds from different regions in Southwest China.

| Regions | The oil content of kernel (%) |
|---|---|
| Yuanmou, Yunnan Province | 55.5 |
| Shuangbai, Yunnan Province | 61.2 |
| Yongren, Yunnan Province | 55.7 |
| Mangshi, Yunnan Province | 56.7 |
| Daluo, Yunnan Province | 51.3 |
| Yongsheng, Yunnan Province | 50.0 |
| Binchuan, Yunnan Province | 52.6 |
| Liuku, Yunnan Province | 51.7 |
| Ningnan, Sichuan Province | 56.5 |
| Liangshan, Sichuan Province | 55.1 |
| Panzhihua, Sichuan Province | 56.4 |

*Source*: Liao [62].

## Appendix B. Determination for the expected values of risk indicators

Table B.1

**Table B.1**
The determination for the expected values of risk indicators.

| Risk indicators | Expected values ($Q_{ci}^*$) | Unit |
|---|---|---|
| C1 | 4.69[a] | Tonne/ha |
| C2 | 100%[b] | |
| C3 | 0[c] | Species |
| C4 | 0 | RMB/ha |
| C5 | 393,334[d] | Hectare |
| C6 | 393,334[e] | Hectare |
| C7 | 70,000 | Tonne |
| C8 | 0 | RMB/tonne |
| C9 | 0 | |
| C10 | 0 | RMB/tonne |
| C11 | 0 | |
| C12 | 4875[f] | RMB/ha |
| C13 | 2750[g] | RMB/tonne |
| C14 | 6000[h] | RMB/ha |

[a] At the level of 4.69 tonne/ha, the benefit of planting jatropha is equal to that of tobacco.
[b,c] The expected values for C1 and C2 are all ideal values, however, they cannot be realized.
[d,e] Based on Table A.6.
[f] Based on Table A.3.
[g] Based on Table A.7.
[h] 6000 RMB/ha is the full amount of subsidy from central government to ensure the management of jatropha cultivation at the lowest level. However, only half amount is received.

## Appendix C. Determination for the primitive risk values of risk indicators

Table C.1

**Table C.1**
The determination for the primitive risk values of risk indicators.

| Risk indicators | Primitive risk values[a] ($W_{ci}$) | Unit |
|---|---|---|
| C1 | −2.44 | Tonne/ha |
| C2 | −43.6% | |
| C3 | 24 | Species |
| C4 | −29,700 | RMB/ha |
| C5 | −381,334 | Hectare |
| C6 | −246,067 | Hectare |
| C7 | −70,000 | Tonne |
| C8 | −2750 | RMB/tonne |
| C9 | 0 | |
| C10 | −819 | RMB/tonne |
| C11 | 40% | |
| C12 | −4875 | RMB/ha |
| C13 | −2750 | RMB/tonne |
| C14 | −3000 | RMB/ha |

[a] The value is determined by formula (1).

## Appendix D. The method of iteration for risk identification

- *Iteration 1*: Literature review
  By literature review, we can summarize hurdles, problems and risks which are included in present papers. Actually, this step has been implemented in previous review section of this paper.
- *Iteration 2*: Review on feasibility study reports of jatropha biodiesel industry
  Generally, a simple risk analysis is included in the feasibility study report, though the report attempts to demonstrate economical, ecological and social feasibility for the necessity of an investment. Therefore, in order to have a complete risk identification, we review the part of risks analysis within feasibility study reports on jatropha biodiesel industry of Panzhihua.
- *Iteration 3*: Questionnaire survey
  Followed as above steps, a questionnaire survey which summarizes and lists risks factors within literature and feasibility study reports has been carried out. In this iteration, as indicated in Table 4, fifty local experts who are familiar with jatropha biodiesel industry in Panzhihua have been interviewed based on the contents of questionnaire. They will select the risks which are most likely to happen and may have serious impact. These people are from different stakeholders.
- *Iteration 4*: Risks confirmation
  According to the result of above iterations, a field survey on current status of jatropha biodiesel industry in Panzhihua has been conducted. This field survey refers to jatropha cultivation survey, household survey, biodiesel production survey, biodiesel marketing survey and government support survey. In order to make the result of risk identification more objectively, the aim of this field survey is to further confirm, select and supplement the risks which are well suited to present status of jatropha biodiesel industry in Panzhihua. Finally, according to the results of above stages, a risk indicators system for risk assessment is finally determined in this iteration.

## Appendix E. The methodology to quantify risk value

1. *Probability quantification*
   The probability of risk occurrence could be assigned with predetermined values based on the study of Edwards and Bowen [58]. Table 5 [58,59] shows the approach to allocate different predetermined values to different probabilities of risk occurrence. Obviously, for risk indicator $C_i$, the value of probability $P_{Ci} \in (0, 1)$.
2. *Severity quantification*
   Generally, semi-quantitative method is often used for assigning predetermined values to the severity of risk [59]. However, the result of this approach could be distorted by subjective factors [58,59], such as people's knowledge, experience, and personality. Therefore, in order to evaluate the risk value more objectively, a method proposed by Yan [60] is adopted in this paper. Accordingly, severity quantification could be calculated by formula (1) [60]:
   $$W_{Ci} = Q_{Ci} - Q_{Ci}^* \quad (1)$$
   where $Q_{Ci}$ defines the primitive value of severity for risk indicator $C_i$, and $Q_{Ci}^*$ denotes the expected value of severity for risk indicator $C_i$. Therefore, $W_{Ci}$ means the primitive risk value of severity for risk indicator $C_i$. In general, the more difference between $Q_{Ci}$ and $Q_{Ci}^*$ means the more severity of risk indicator $C_i$ [60].
3. *Quantify the possibility for risk control*
   Define the value of $W_{Ci} \in [0, 1]$, therefore, the possibility for risk control could be calculated by formula (2):
   $$D_{Ci} = 1 - W_{Ci} \times P_{Ci} \quad (2)$$

where $D_{Ci}$ means the possibility for risk control. Actually, $D_{Ci} \in [0, 1]$. In general, the higher value of $D_{Ci}$ denotes the more possibility for risk control.

## Appendix F. The TOPSIS method to determine the priority for risk response

- *Step 1*: Establish the primitive decision matrix in which contains all the identified risks of jatropha biodiesel industry in Panzhihua.

$$W_{Ci} = (w_{ij})_{m\times n}, \quad i = 1, 2, 3, \ldots, m; \quad j = 1, 2, 3, \ldots, n \tag{3}$$

- *Step 2*: According to Li [57] and Yan [60], we normalize the primitive decision matrix $W_{Ci} = (w_{ij})_{m\times n}$ by the following formulas [57,60]:

  For positive indicators:

$$W^*_{Ci} = \frac{w_{ij} - \min w_{ij}}{\max w_{ij} - \min w_{ij}} \tag{4}$$

  For negative indicators:

$$W^*_{Ci} = \frac{\max w_{ij} - w_{ij}}{\max w_{ij} - \min w_{ij}} \tag{5}$$

  where $W^*_{Ci}$ means normalized decision matrix.
- *Step 3*: Determine the weighted normalized decision matrix.

$$a_{ij} = \omega_j W^*_{Ci}, \quad i = 1, 2, 3, \ldots, m; \quad j = 1, 2, 3, \ldots, n \tag{6}$$

  where $\omega_j$ denotes the weight for the *j*th attribute of risk indicator $C_i$.

$$\sum \omega_j = 1, \quad j = 1, 2, 3, \ldots, n \tag{7}$$

- *Step 4*: Determine the positive and negative ideal solutions.

$$Q^+ = \{a_1^+, \ldots, a_n^+\} = \max a_{ij}, \quad i = 1, 2, 3, \ldots, m; \quad j = 1, 2, 3, \ldots, n \tag{8}$$

$$Q^- = \{a_1^-, \ldots, a_n^-\} = \max a_{ij}, \quad i = 1, 2, 3, \ldots, m; \quad j = 1, 2, 3, \ldots, n \tag{9}$$

  where $Q^+$ is the positive ideal solution and v is the negative ideal solution.
- *Step 5*: Calculate the Euclidean distances of each identified risk from the positive and negative ideal solutions.

$$L^+ = \sqrt{\sum_{j=1}^{n} (a_{ij} - a_j^+)^2}, \quad i = 1, 2, 3, \ldots, m \tag{10}$$

$$L^- = \sqrt{\sum_{j=1}^{n} (a_{ij} - a_j^-)^2}, \quad i = 1, 2, 3, \ldots, m \tag{11}$$

- *Step 6*: Calculate the relative closeness of each identified risk to the positive ideal solution $Q^+$.

$$N_i = \frac{L^-}{L^+ + L^-}, \quad i = 1, 2, 3, \ldots, m \tag{12}$$

- *Step 7*: Determine the priority for risk response according to the relative closeness to the positive ideal solution $Q^+$.

## References


[1] Prueksakorn K, Gheewala SH, Malakul P, Bonnet S. Energy analysis of Jatropha plantation systems for biodiesel production in Thailand. Energy for Sustainable Development 2010;14:1–5.

[2] Prueksachat R. Physic nut (Jatropha curcas L.) plantation and development for substituting of diesel oil (in Thai). Nontaburi, Thailand: Neon Book Media; 2006.

[3] Report of the committee on development of "BIOFUEL" planning commission. New Delhi: Government of India; 2003.

[4] http://news.china.com/zh_cn/news100/11038989/20070311/13982829.html; 2007.

[5] Weyerhaeuser H, Tennigkeit T, Su YF, Kahrl F. Biofuels in China: an analysis of the opportunities and challenges of jatropha curcas in Southwest China. ICRAF Working Paper Number 53; 2007. http://www.worldagroforestrycentre.org/sea/Publications/Files/workingpaper/WP0088-07.PDF.

[6] Tang P, Luo JX, Wang XJ. Exploitation and research progress for jatropha curcas. Panzhihua Sci-Tech and Information 2007;32(3):22–8.

[7] Openshaw K. A review of Jatropha curcas: an oil plant of unfulfilled promise. Biomass and Bioenergy 2000;19(1):1–15.

[8] Huang X, Li YP, Wang F, Du CX. The climate characteristics and the exploitation of the light and heat resource in winter in Panzhihua. Journal of Sichuan Meteorology 2006;26(1):20–5.

[9] Mao JX, Lv ZD, Du CX, Wang YB. The function of weather forecast for the establishment of characteristic agriculture of Panzhihua. Panzhihua Sci-Tech and Information 2010;35(2):28–31.

[10] Liu X, Ye M, Fang YM, Ye X. Reconsideration upon biodiesel industry of jatropha curcas-a case study of Panzhihua. Forestry Economics 2010;7:86–9.

[11] Luo JX, He XF, Gu YJ, Tang P, Cao XJ, Yang PJ. Study on phenotypic diversity of natural populations of jatropha curcas in Panzhihua area, Sichuan Province. Journal of Southwest Forestry College 2008;28(6):31–5.

[12] The Science and Technology Bureau of Panzhihua; 2007. http://218.89.108.58/pt1/kjxxw/html/news/news_view.asp?newsid=1416.

[13] Chengdu Business Paper; 21.08.2008. http://sichuan.scol.com.cn/sczh/20080821/200882172323.htm.

[14] The People's Government of Panzhihua. http://www.panzhihua.gov.cn/index.shtml.

[15] Panzhihua Local Chorography. http://www.panzhihua.gov.cn/zjpzh/pzhsz/depzrhjyzy/206284.shtml.

[16] Li YP, Du CX, Chen YQ, Li FQ, Mao JX, Lv ZD. An assessment of solar energy resources in Panzhihua. Plateau and Mountain Meteorology Research 2009;29(1):44–9.

[17] Wang RX, Peng PH. The agriculture geologic background and eco-agriculture development in Panzhihua Area. Journal of Shanxi Agricultural Sciences 2009;37(8):47–50.

[18] Pan HP, Xiao PJ. Scientifically exploit the agricultural resources, develop the characteristic agriculture of Panzhihua. In: Conference on the exploitation and utilization for characteristic biological resources in Panzhihua Area. 2007.

[19] Panzhihua Statistics Bureau. Statistical communiqué of Panzhihua on the national economic and social development; 2009, http://www.pzhstats.gov.cn/_WebDataView.asp?id=1066.

[20] Sichuan Statistics Bureau; 2009. http://www.sc.stats.gov.cn/zxtjxx/201002/t20100208_108160.html.

[21] Wu WG, Huang JK, Deng XZ. Potential land for plantation of Jatropha curcas as feedstocks for biodiesel in China. Science China Series D: Earth Science 2009, doi:10.1007/s11430-009-0204-y.

[22] Lu Y, Wang ZX. A SWOT analysis of producing biodiesel from jatropha curcas in Yunnan. Resource Development and Market 2009;25(6):534–7.

[23] Zhang GW, Peng Y, Huang M. Existing problems and countermeasures for jatropha curcas L. industrialization in China. Journal of Anhui Agricultural Science 2009;37(8):3821–3.

[24] Yu B, Tang XZ, Zhu ZZ, Yang JY, Zou X, Pang DB, et al. The current situation and countermeasures of jatropha curcas L. in Sichuan Province. Sichuan Forestry Exploration and Design 2007;3:16–8.

[25] Ye M, Li CY, Francis G, Makkar HPS. Current situation and prospects of jatropha curcas as a multipurpose tree in China. Agroforestry Systems 2009;76:487–97.

[26] Yu L, Zhang HO, Zhou ZJ, Huang ZQ, Zhou YJ, Wang ZY, et al. Survey of harmful organisms on jatropha curcas L. in Panzhihua City. Modern Agricultural Science and Technology 2010;13:164–9.

[27] Wu JR, Ma HC, Liu TT, Tang JR, Su HF, Xu H. Investigation on the diseases and pest insects of jatropha curcas in dry-hot valley. Forest Pest and Disease 2008;27(4):18–21.

[28] Fei SM, Chen XM, He YP. Prospects of studies on jatropha curcas biodiesel in Sichuan. Biomass Chemical Engineering 2006;40(12):193–9.

[29] Luo CY, Zhang JP. Review the development of jatropha curcas bioenergy industry from the perspective of agricultural comparative benefit-a case study of Panzhihua. Panzhihua Sci-Tech and Information 2007;32(3):17–21.

[30] He YP, Fei SM, Xu J, Chen XM, Cai XH, Lei CH, et al. The inflorescence structure and dynamics of male and female flowers of jatropha curcas in Sichuan Province. Journal of Sichuan Forestry Science and Technology 2008;29(2):1–8.

[31] Wu WG, Li NY. Forest-based biodiesel development: target, current status and challenges. Scientia Silvae Sinicae 2009;45(11):141–7.

[32] Zheng BC, Wang DJ. Technology exploitation and techno-economics analysis for jatropha biodiesel production by solid alkali catalysts. In: Conference on the exploitation and utilization for characteristic biological resources in Panzhihua Area. 2007.

[33] Wang JX. Discussion on economic benefit and related policy of woody bio-diesel project. Chemical Industry 2008;26(1):8–10.

[34] Min EZ, Tang Z, Du ZX, Wu W. Perspective of biodiesel industry in China. Engineering Science 2005;7(4):1–4.

[35] Min EZ, Yao ZL. The challenges and countermeasures for the biodiesel industry in China. Natural Gas Industry 2008;28(7):1–4.

[36] Li X, Li ZL, He XY, Wang F, Jiang JC. Study on producing biodiesel fuel from jatropha curcas oil sources catalized by whole cell biocatalyst. Modern Chemical Industry 2008;28(9):57–9.
[37] Research Institute of Petroleum Processing, Sinopec Corp. Biodiesel blend stock (BD100) for diesel engine fuels; 2006, http://www.cth.cn/Lab/_files/BD100.pdf.
[38] Yin FS, Zheng YK. Status of biodiesel industry in China. Detergent and Cosmetics 2008;31(2):1–3.
[39] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Standardization Administration of the People's Republic of China. Biodiesel blend stock (BD100) for diesel engine fuels (GB/T20828-2007). Beijing: China Standard Press; 2007.
[40] Wu CZ, Yin XL, R.M.B S Z.H., Zhou ZQ, Zhuang XS. The development of bioenergy technology in China. Energy 2010;35:4445–50.
[41] Ji X, Wang X, Zhang XB, Li HH, Ji JP, Liu JS, et al. Some main problems for the development of China biodiesel industry. International Petroleum Economics Monthly 2007;15(2):27–30.
[42] Dhanda KS. Farmers' experiences, problems, and suggestions on jatropha plantation and cultivation. In: International conference on biofuels. 2004.
[43] The Energy and Resources Institute India Habitat Centre. Liquid biofuels for transportation: India country study on potential and implications for sustainable agriculture and energy. New Delhi; 2005. http://www.bdbe.de/downloads/PDF/fachinformationen/biofuels-for-transportation-in-india.pdf.
[44] Biswas PK, Pohit S, Kumar R. Biodiesel from jatropha: Can India meet the 20% blending target? Energy Policy 2010;38:1477–84.
[45] Gonsalves JB. An assessment of the biofuels industry in India. United Nations conference on trade and development; October 18, 2006. http://www.sciencerepository.org/in_documents/IN1095.pdf.
[46] Mandal R. Energy – alternate solutions for India's needs: biodiesel. Planning Commission, Government of India; 2005.
[47] Wiskerke WT, Dornburg V, Rubanza CDK, Malimbwi RE, Faaij APC. Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shinyanga Region in Tanzania. Renewable and Sustainable Energy Reviews 2010;14:148–65.
[48] Eijck JV, Romijn H. Prospects for jatropha biofuels in Tanzania: an analysis with Strategic Niche Management. Energy Policy 2008;36:311–25.
[49] Tomomatsu Y, Swallow B. Jatropha curcas biodiesel production in Kenya: economics and potential value chain development for smallholder farmers. Working Paper # 54, World Agroforestry Centre. World Agroforestry Centre; 2007. http://www.worldagroforestry.org/downloads/publications/PDFs/WP15396.PDF.
[50] Thun JH, Hoenig D. An empirical analysis of supply chain risk management in the German automotive industry. International Journal of Production Economics 2009, doi:10.1016/j.ijpe.2009.10.010.
[51] Brittaine R, Jatropha Lutaladio N. A smallholder Bioenergy crop – the potential for pro-poor development. Integrated Crop Management. Rome: Food and Agriculture Organization of the United Nations; 2010.
[52] Wang Q. Research on venture capital and resources of woody oil-bearing plant project in China. Master Dissertation, Beijing Forestry University, Beijing, China; 2008.
[53] Hertz DB, Thomas H. Risk analysis and its applications. Chichester: John Wiley & Sons; 1983.
[54] Nieto-Morote A, Ruz-Vila F. A fuzzy approach to construction project risk assessment. International Journal of Project Management 2010, doi:10.1016/j.ijproman.2010.02.002.
[55] Hallikas J, Karvonen I, Pulkkinen U, Virolainen VM, Tuominen M. Risk management processes in supplier networks. International Journal of Production Economics 2004;90:47–58.
[56] Adams PW, et al. Barriers to and drivers for UK bioenergy development. Renewable & Sustainable Energy Reviews 2010, doi:10.1016/j.rser.2010.09.039.
[57] Li SM. Research on appraising the managing priority of risk. Master Dissertation, Southeast University, Nanjing, China; 2006.
[58] Edwards PJ, Bowen PA. Risk management in project organisations. Elsevier: Butterworth Heinemann; 2005.
[59] Wyk RV, Bowen P, Akintoye A. Project risk management practice: the case of a South African utility company. International Journal of Project Management 2008;26:149–63.
[60] Yan Y. Study on project risk management of the forestry ecological engineering in China. Doctor Dissertation, Beijing Forestry University, Beijing, China; 2008.
[61] Hwang CL, Yoon K. Multiple attribute decision making: methods and application. Berlin: Springer; 1981.
[62] Liao JX. Study on the biological character and bioactive components of jatropha curcas L. in the area of Panzhihhua. Master Dissertation, Sichuan University, Chengdu, China; 2003.
[63] Chen XY. The utilization of solar energy and the development of LED – a case study of Panzhihua. Silicon Valley 2010;11:30.
[64] Provided by Panzhihua Forestry Bureau.
[65] Wen Y. Consider on the meaning, current situation and strategy for the development of bioenergy plants in Sichuan. In: Conference on the exploitation and utilization for characteristic biological resources in Panzhihua Area. 2007.
[66] Provided by Panzhihua Price Bureau; 2007. http://www.pzhjg.gov.cn/.